Solid Waste Management at University Campus (Part 6/10): Preliminary Estimation of Combustibility and Energy Potential of the Waste

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Abstract
This is a-sixth-piece in a-series of 10. To-examine waste-combustibility, its Moisture-Content (MC), Ash-Content, and Volatile-matter, were established, in-accordance-with the-UNEP (2015); ASTM D3174-12; and ASTM D1102: 2013 alongside-with ISO 562: 2010, respectively. A-Tanner-triangle-concept and its-combustibility-requirements informed the-study, and enable to-visualize the-combustibility potential, graphically. The-study established that, for the-waste, at the-subject-university: (a) MC ranges from 10.76 to 57.66 %, with an-average of 36.84%; (b) Ash-content ranges from 14.1 to 42.79%, averaging 23.11%; (c) Volatile-matter ranges from 21.78 to 51.34%, with an-average of 38.03%; (d) From the-graphical- judgment of the-Tanner triangle, it was projected that: (i) 37 % by weight, of the-total-waste, is high in-moisture-content (57.66 %), and according to the-Tanner-combustibility-requirements cannot be combusted, without auxiliary-fuel (e.g., autothermic-combustion), and hence should-be composted, or vermicomposted, or anaerobically-digested, to-generate biogas, and produce a-stabilized-organic-humus, or Microbial-Fuel-Cells (MFCs) can-be-used for electricity-production; (ii) 41% of the-total-waste is combustible; and (e) 87.8% of the-solid-waste has the- capability of being-converted to heat-energy. Waste-to-Energy (WtE) technologies, alongside with selected-myths, surrounding them, were, hence, reviewed. The-current-study is largely-preliminary, therefore, further-studies, such-as: comprehensive Proximate and Ultimate-Analysis of solid-waste, generated by the-university, is further recommended. In-addition, the-study recommends to-conduct a-feasibility-assessment of WtE-technologies, at the-university, via decision-matrix. The-findings of this-research provide a-necessary-baseline-data, for the-four-subsequent-studies, in the-series, and also, hopefully, add to-the-body of knowledge, on the-subject-matter.

Keywords: Tanner triangle; Moisture Content, Ash; Volatile matter, Waste-to-Energy (WtE), Composting, Vermicomposting.

1. Introduction.
It-is-estimated that global-waste-generation will-double by 2025, to-over 6 million-tons of waste, per-day, and the-rates are not expected to-peak by the-end of this-century. By 2100, global-waste-generation may hit 11 million tons, per-day (World-Energy-Council, 2016). Municipal-solid-waste (MSW) management-system aims to-handle health, environment, aesthetic, land-use resources, and economic-concerns, related-to improper disposal of waste (Al-Waked et al., 2014; Ouda & Cekirge, 2014; Nemerow, 2009). Population, urbanization-growth, and the-rise of standards of living, have all dramatically-accelerated the-municipal solid-waste (MSW) generation in-developing-countries (Guerrero et al., 2013; Minghau et al., 2009). Developing-countries, however, are not able to-cope-with the-MSW-generation-growth, and open-landfills remain the-dominant-method of waste-disposal (Ouda et al., 2013; Ouda, 2013).

In-many-countries, MSW-management has often been-regarded as a-public-service with-low priority: a-nuisance and a-burden (Starovoytova, 2018 a; 2018 b; Mutz et al., 2017). In-this-regard, the-2015 United-Nations Sustainable-Development-Goals (SDGs), as-well-as UN Habitat’s New-Urban Agenda (2016), call for improvements in-WM-practices, as a-basic-service, to citizens.

On-the-other-hand, Energy is a-critical-issue for Africa, where large-number of people does not have access to-reliable-energy (Scarlat et al., 2015). For-example, according-to Kenya: Energy Profile (2012), Kenya currently has a-national-electrification-level below 15%. Kenya’s energy-sources consist of imported fossil-fuels and renewable-sources, which include biomass, hydro, geothermal, solar, and wind. Total-installed-electricity-capacity (2010) is 1,429 MW (Hydro-electric -- 52.1%; Geothermal -- 13.2%; Conventional-Thermal -- 32.5%; Wind, and Others -- 2.2%) (IRENA, 2010). Only about 5% of the-rural-households have access-to electricity, while biomass, mainly-fire-wood, accounts for 77% of the-total-energy, consumed. In-addition, the-Ministry of Energy, in-Kenya, has identified several-long and short-term challenges, such-as: Inadequate-power-supply-capacity, due-to rise in-demand for electricity, which is growing faster, than the-ability to-install additional-generation-plants; Over-dependence on hydro-power, which exposes the-country to-power-rationing, due-to extreme-weather-conditions, such-as drought; Shortage of transformers and overstressed-distribution-network; Dependence on donor-funding for various-projects; Long-delays in-development of power-infrastructure,
because building of power generation, transmission and distribution-network is capital-intensive and takes inordinately-long-time from-conception to-commissioning; Low-investments in power-generation by private-investors; Inadequate-sea-port-facilities for handling imported-coal and natural-gas, which are cheaper primary-energy-resources, than petroleum oil-based-fuels for power-generation; High and ever-rising-international-prices of fossil-fuels; Obsolete oil-refinery-system; Conflict with food-security-issues, when developing the-bio-diesel-industry; and Unrealistic-demands by local-communities where energy-resources, like coal, gas, and oil, are discovered (https://softkenya.com/kenya/challenges-facing-energy-sector-in-kenya/).

1.2. Waste-to-energy (WtE) as a-compromise, between high-energy-demands and the-state of the-environment.

The-compromise, between the-energy and the-environment, is a-recent-controversial-issue. Generally, people assume that energy-generation and environmental-protection-activities contradict each-other. More-clearly, most of the-energy-generation-systems exploit the-natural-resources and are a-hazard to the-environment, in-terms of source-depletion and environmental-contamination. One of the-solutions of this-problem is to-implement synergy, between environmental-protection and energy-generation (Alpaslan et al., 2001). Resource-recovery, from waste, can play a-role, in-minimizing the-impact of energy-resources, along-with raising-the-local-source of energy (Scarlat et al., 2015).

There are four-principal-methods for resource-recovery or disposal of MSW (Themelis et al., 2002): (1) Recovery of materials: Recovered (by recycling) paper, plastic, rubber, fiber, metal, and glass, can be re-used to-produce similar-materials; (2) Recovery of energy: Recoverable-energy is stored, in-chemical-form, in all-MSW-materials, that contain hydrocarbons; this includes everything, except metals, glasses, and other-inorganic-materials (e.g., ceramics, plaster, etc.). By-combusting such-wastes (via Mass Burn WtE Plants; Fluidized-Bed WtE Plants; Refuse Derived Fuel (RDF), electricity and steam can-be-generated; (3) Bioconversion: The-natural-organic-components of MSW (e.g., food and plant wastes, paper, etc.) can be composted aerobically (i.e., in-the-presence of oxygen) to carbon-dioxide, water, and a-compost-product, that can be used as soil-conditioner. On-the-other-hand, anaerobic-digestion, or fermentation, produces methane, or alcohol and a-compost-product; this method provides an-alternate route for recovering some of the-chemical-energy, stored in-the-hydrocarbon-fraction of MSW; and (4) Direct disposal methods should be used for any-fraction of the-MSW that is not or cannot be subjected to any of the-above-three-methods, plus any-residuals from these-processes (e.g., ash from combustion). The-methods involve sanitary-landfill, lagooning, disposal into-surface-waters, in-deep-wells, or at-sea/ocean. In-developed-countries, the-use of direct-disposal-methods, at-present, is highly-restricted, to well engineered-sites and selected-categories of non-objectable-wastes. In-contrast, in-most-developing countries indiscriminate-waste-dumping is a-common-practice.

Waste-managers and decision-makers, in-developing and emerging-countries, have-to-respond to these-challenges, and in-recent-times, waste-to-energy (WtE) has been increasingly-viewed as-a-solution to the-problems, derived-from rising-waste-quantities, indiscriminate waste-dumping, in-expanding-cities, as-well-as rapidly-growing-energy-demands. WtE refers to a-family of technologies, which treat waste, to-recover-energy, in-the-form of heat, electricity, or alternative-fuels, such-as biogas. The-scope of the-term ‘Waste-to-Energy’ is very-wide, encompassing a-range of technologies of different-scales and complexity. These can include the-production of cooking-gas, in-household-digesters, from organic-waste; collection of methane-gas, from landfills; thermal-treatment of waste, in-utility-size incineration-plants; co-processing of Refuse-Derived-Fuel (RDF), cement-plants, or gasification, among-others (Moya et al., 2017). Waste-to-energy (WtE) technologies are assessed in-this-study.

1.3. Previous-research and purpose of this-study.

Recent-study by Starovoytova & Namango (2018 b) have revealed, that both; students and vendors: (i) have recognized SWM as a-major-problem, at-the-campus; and (ii) perceived the-campus as-dirty and very-dirty. Another-study by Starovoytova (2018 c) estimates, that the-subject-university-campus generates about 5, 111.65 tons, of mixed-waste, per-year, on-average. Out of which: (i) Food-waste, which is compostable, accounts to 1,891.31 tons/per year; and (ii) Recyclables, included: paper (mixed & corrugated) - 32% (1,635.73 tons/per year); glass - 13% (664.43 tons/per year); plastic and metals, each - 8% (408.93 tons/per year); and E-waste and other-non-combustibles, each - 1% (51.12 tons/per year). Her-study is also revealed, that:” Every-day the-university is literally throwing-away profit, as the-waste is just disposed-off at the-dumpsite, without any-formal waste-reduction, at-source, recycling, or composting”. The-same-study also recommended further-studies on Moisture-Content and Energy-Potential of the-waste, at-the-campus, as a-next-logical-step.

The-need to-increase the-share of renewable-energy and reduce GHG-emissions, along-with raising-environmental-consciousness, to-protect the-environment from polluting and unsustainable-practices, such-as indiscriminate-waste-dumping, practiced at-the-university, will in-turn, call for noble-approaches. According to the-World-Energy-Council (2016), “treating residual-waste with various Waste-to-Energy (WtE) technologies is a-viable-option for disposal of solid-waste and energy-generation. Many-factors, however, will influence the-

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choice of technology, and every-region will have-to properly-assess its-specific-context, to-implement the-most-reasonable-solution”. In-this-regard, a-study, in-the-university-context, is necessary, to-identify the-customized-and-most-practicable-solutions, to-current-wasteful-SWM-practices.

To-examine different-alternatives to current-SWM-practices, at the-university, such-as, (WtE)-technologies, currently available, first, the-assessment of the-waste-combustibility and Energy-potential of the-waste, at subject-university should-be-conducted, which in-turn require examination of selected-waste properties. Chandrappa & Das (2012), specified important-chemical-properties, measured for solid-waste, such-as: (1) moisture (water-content can change chemical and physical-properties); (2) volatile-matter; (3) ash; (4) fixed-carbon; (5) fusing-point of ash; (6) calorific-value; and (7) percent of carbon, hydrogen, oxygen, sulphur, and ash. Besides, the-major physical-characteristics, measured in-waste, are: (1) bulk-density; (2) size-distribution of components; and (3) moisture-content. Other-characteristics, which may-be-used, in-making-decision about SWM, are: (1) color; (2) voids; (3) shape of components; (4) optical-property; (5) magnetic-properties; (6) flammability; (7) electric-properties; and (8) putrescence of solid-waste (Buekens, 2005). This-study will be limited-to such-parameters-as: moisture-content, ash, and volatile-matter.

According to Islam (2016):”... characteristics of the MSW stream, like … moisture-content, are critical-factors to determine energy recovery alternatives”. The-next-section elaborates on the-waste moisture-content.

Moisture-content (MC) has a-great-influence on the-heat of combustion, as-well-as in-the-biological-processes of organic-matter. MC plays an-important-role in-understanding the-nature of the-waste, as high-MC indicates presence of higher-fraction of organic-materials. MC is a-key-factor that greatly-shapes decisions, involved in-the-conversion of organic-waste into-compost and biogas, making use of solid-waste as a-fuel, and designing landfills or incineration-plants (Eyinda & Aganda, 2013). In-particular, MC is a-dominant-factor in-aerobic-composting (Liang et al., 2003). It provides better degradation of organic-matter, and maintains temperature for longer-time-period. Moisture is important for the-activity of microbes, because it increases the-rate of metabolism. The-activity of microbes is at-minimum, when low-moisture is provided (Tiquia et al., 1996). The-moisture is also inversely proportional to the-temperature and the-microbe-activity (Makan et al., 2012). MC is one of the-critical design and operating-parameters, used in-compost-engineering-systems. As a-result, MC-analysis is one of the-most-commonly performed analytical-methods on solid-waste (Ozcan et al., 2016).

On-the-other-hand, moisture increases the-weight of solid-wastes, and thereby, the-cost of collection and transport. In-addition, moisture-content is a-critical-determinant in the-economic-feasibility of waste-treatment by incineration (Vesilind et al., 2002), because wet-waste consumes more-energy (for evaporation of water and in-raising the-temperature of water-vapor), hence, wastes should be insulated from rainfall or other-extraneous-water. For-example, combustion of solid-waste depends on MC; high-moisture-content results in low-net-energy from the-waste i.e., low-calorific-value (Eyinda & Aganda, 2013).

Many-scholars, all-over-the-globe, have conducted analysis of MC, Combustibility, and Energy-potential of waste, such-as: Moya et al., 2017; Mugo et al., 2016; Islam, 2016; Dolgen et al., 2015; Ezeah et al., 2015; Ouda et al., 2015; Omari, 2015; Scarlat et al., 2015; Al-Waked et al., 2014; Omari et al., 2014; Ouda & Cekirge, 2014; Khamala & Alex, 2013; Katiyar et al., 2013; Das & Bhattacharyya, 2013; Medina, et al., 2013; Ellyin, 2012; Amber et al., 2012; Yildiz et al., 2012; Ferreira et al., 2012; Kothari et al., 2010; Ryu, 2010; Tsai & Kuo, 2010; Salomon & Lora, 2009; Chang & Davila, 2008; Cheng et al., 2007; Kathiravale et al., 2004; et al., 2003; Themelis et al., 2002; Mbuligwe, 2002; Kumar, 2000; and Leão & Tan, 1997. Studies, at university-context, however, are deficient. In-the-light of the-above-information, this-study is focused on Combustibility, and Energy-potential of waste, at the-subject-university. Its-findings will hopefully assist in the-decision-making on ISWM-system, to-be-developed, for-the-campus.

2.1. Background.
The-study was conducted at the-Moi-University (MU), situated at Kesses-Constituency, the-Uasin Gishu-County, Kenya. MU is the-second-largest-public-university, after the-University of Nairobi. As of 2007, it had over 20,000 students, including 17,086 undergraduates. It operates eight-campus and two-constituent-colleges (Starovoytova & Cherotich, 2016 b). The-study was conducted over a-four-week sampling-period, in-2017 calendar-year, across the-MU, main-campus.

Analogous to Starovoytova (2017), interested-readers could-refer to Starovoytova et al. (2015) to-find informative-synopsis regarding Kenya, and its-educational-system. Besides, study by Starovoytova & Cherotich (2016 a), provides valuable-particulars, on MU, where the-study was conducted. The-geographical-position on the-subject-university can be accessed via Starovoytova & Namango (2018 a).

2.2. Determination of Combustibility.
The-ability of waste to-sustain a-combustion-process, without supplementary-fuel, depends on a-number of physical- and chemical-parameters, of which the-lower (inferior) calorific-value is the-most-important. The-
minimum-required lower-calorific-value, for a-controlled-incineration, also depends on the-furnace design. The-
combustibility of MSW is determined by analysis and heating-value of MSW, which is the-ash and water-free
calorific-value (\(H_{awf}\)) expresses the-lower-calorific-value of the-combustible-fraction (ignition-loss of dry-
sample). For direct-incineration and energy-recovery, the-waste calorific-value should-be at least 2000-2500
kcal/kg, and 1500-1600 kcal/kg for the-combustion, without additional-fuel. If the-heating-value is below 1200
cal/kg, it is understood that the-solid-waste cannot be economically burned. The-other-method of
combustibility-determination is via Tanner-combustion-triangle (Worrel & Vesilind, 2008). In-this-study, the-
combustibility was determined graphically via Tanner-triangle.

2.3. Determination of Moisture Content (MC).
Currently, many-moisture-meters are available, for the-determination of MC, in the-field. This-study, however,
used proven, traditional laboratory oven-drying testing-method. According-to Komilis et al. (2012), oven-
drying is always part of the-sample-preparation-protocol for quantitative-analysis. Although time-consuming,
this-method is precise, straight-forward, and can-be-used to-analyze many-samples, simultaneously. In-the-wet-
weight-method of measurement, the-moisture-content (MC), in a-sample, was expressed as-a-percentage, of the-
weight, of the-material, when wet, whereas in the-dry-weight-method, it was expressed as-a-percentage of the-
weight of the-material, when dry. The-study used the wet-weight method in-accordance-with the-UNEP,
Mapping Solid Waste – II (2015), with no correction done, for cross-contamination of wastes.

Apparatus used for the-determination of MC, are: (i)  Weighing-device: a-balance, sensitive to 0.1 % of the-
mass of the test-sample, and having a-capacity equal to, or greater than, the wet-mass of the-sample to-be-tested;
(ii) Drying-device: an-oven, with thermostatically-controlled heating-chamber, capable of maintaining a-
temperature of 85 ± 5°C; (iii) Heat-resistant gloves/mitts, and pot-holders, to-remove-samples, from the-oven;
(iv) Aluminum-Foil; (v) Clean-plastic-bags; and (vi) Stickers and marker-pen for labeling the-samples.

Representative-samples were collected-randomly, from the-identified-waste-generators, labeled, put in
separate-clean-plastic-bags, and brought to the-testing-laboratory, for-testing, within the-same-day. Certain-
amounts of waste, from each-sample, were inspected for signs of cross-contamination-with waste-
liquids or rainwater, and then weighed to an-accuracy of not less than 0.10 kg, and then laid-down as-a-carpet that is max 3
cm-thick, in an-aluminum-foil; the-weight was recorded as W1. Several-samples were then positioned into
preheated-fan-assisted-oven, to-allow the-maximum-air-circulation and exhaust of the-moisture-laden-air, and
dried to constant-mass at 85 ± 5°C, for 48hours. Afterwards, the-samples were removed from the-oven, and kept
in-desiccators, to-allow to-cool, naturally, for another 48 hours. Then the-samples were re-weighed and recorded,
as W2. The-moisture-content (% H\textsubscript{2}O) is then calculated as follows:

\[
% \text{H}_2\text{O} = \frac{(W_1 - W_2)}{W_1} \times 100
\]

2.4. Determination of Volatile Matter.
Volatile-matter of a-municipal-solid-waste is a-vapor, released when the-waste is heated. The applicable
standards, such-as, ASTM D1102: 2013 and ISO 562: 2010, were followed-in for determination of volatile-
matter. The previous-sample, used for moisture-content-determination, was again heated in a-covered crucible, to-avoid
contact with air, during de-volatilization. The-covered-crucible was placed-into a-furnace at 950°C for 2 hours.
Then the-crucible was taken-out, and cooled in-desiccator. The-weight difference, due-to de-volatilization was
referred as volatile-matter, calculated by the-formula below:

\[
\text{Volatile Matter (\%) = } \frac{(\text{Initial weight} - \text{Final weight}) \times 100}{\text{Initial weight}}
\]

2.5. Determination of Ash content.
Ash is the-inorganic solid-residue, left after the-waste is completely-burned. ASTM D3174 - 12 Standard-
procedure was used for ash-determination. The-remaining-waste-sample from volatile-matter examination was
weighted, and placed into the-muffle-furnace at 750°C for 1 hour for combustion, until the-waste is completely-
converted-to-ash. When all-carbon was burnt, the-sample was cooled to-room temperature, and re-weighted.
Ash-content was calculated as:
2.6. Determination of Energy potential
The combustion of waste liberates energy in the form of heat. A proportion of this energy is used to dry the waste first (as the moisture content has to be eliminated). The remaining energy can then be used to generate power and some useful work. This therefore illustrates that the higher the moisture content, the smaller the energy available for doing meaningful work. This available energy can be computed as follows (Eyinda & Aganda, 2013):

The NET-energy, that can be extracted, from waste is given by: $E_{net} = E_{gross} - E_{dry}$

Where: $E_{net}$ = Net energy; $E_{gross}$ = gross energy; and $E_{dry}$ = Energy used to dry the waste.

From the equation above, $E_{dry} = E_{gross} - E_{net} - H_s$ (Eyinda & Aganda, 2013).

Where: $E_{dry}$ = the energy, required to dry the solid waste, $H_{fg}$ = the heat of vaporization; and $H_s$ = the energy, used to raise the temperature of the waste-water, from the initial temperature to vaporization temperature.

To find $H_s$, the following equation is given: $H_s = M_w x C_p x (T_s - T_i)$ (Eyinda & Aganda, 2013).

Where: $M_w$ = mass of moisture in solid waste; $C_p$ = Heat Capacity of water; $T_s$ = Vaporization Temperature; and $T_i$ = Initial Temperature.

Finding latent heat of vaporization is done by $H_{fg} = M_w x H_{fg}$ (Eyinda & Aganda, 2013).

To determine the Net Energy, the following formula was derived: $E_{net} = (M - M_w) x C_v$ (Eyinda & Aganda, 2013).

Where: $C_v$ = Calorific value of dry waste;

Therefore: $E_{net} = (M - M_w) - [(M_w C_p (T_s - T_i)) + M_w H_{fg}]$ (Eyinda & Aganda, 2013).

2.7. Data Analysis.
Microsoft Excel, for Windows XP Professional 10; and GraphPad Prism 6.00 for Windows, were used for data analysis. Descriptive statistics were also used to highlight patterns and general trends, in the data sets.

3. Results and Analysis.
3.1. Moisture Content (MC).
Figure 1 shows waste-samples arrangement, in the oven, during MC determination, while Table 1 shows the results for MC, for 5 waste generators, at MU, and Figure 2 shows comparative graph of MC.

![Figure 1: Arrangement of samples in the oven.](image-url)
Table 1: Moisture Content for 5 waste generators.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Stage Market</th>
<th>Laboratories</th>
<th>Administrative Offices</th>
<th>Eateries</th>
<th>Hostels</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wet weight (Ww), kg</td>
<td>1.035</td>
<td>0.790</td>
<td>1.310</td>
<td>0.685</td>
<td>1.360</td>
</tr>
<tr>
<td>Dry weight (Wd), kg</td>
<td>0.600</td>
<td>0.705</td>
<td>0.830</td>
<td>0.290</td>
<td>0.855</td>
</tr>
<tr>
<td>Weight difference (Ww-Wd), kg</td>
<td>0.435</td>
<td>0.085</td>
<td>0.480</td>
<td>0.395</td>
<td>0.505</td>
</tr>
<tr>
<td>Moisture Content, %</td>
<td>42.03</td>
<td>10.76</td>
<td>36.64</td>
<td>57.66</td>
<td>37.13</td>
</tr>
</tbody>
</table>

Figure 2: Comparison of MC.

3.2. Summary of results for all-the-parameters.
Table 2 shows the-summary of the-results.

Table 2: Summary of the-results.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Units</th>
<th>Range</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moisture Content (MC)</td>
<td>%</td>
<td>10.76 - 57.66</td>
<td>36.84</td>
</tr>
<tr>
<td>Ash Content</td>
<td>%</td>
<td>14.1 – 42.79</td>
<td>23.11</td>
</tr>
<tr>
<td>Volatile-matter</td>
<td>%</td>
<td>21.78 – 51.34</td>
<td>38.03</td>
</tr>
</tbody>
</table>

The-annual average-temperature of Eldoret, Uasin-Gishu-County is typically 16.6 °C (Climatemps, 2017). To-work-out the-net-energy-potential, the-following-values are used: The-Calorific-Value of the-sampled waste was-taken as 12.48 MJ/Kg. This-Calorific-Value was determined, for solid-waste, in-Nairobi, using the-guidelines provided by the-British-Standard, B.S. 1016: Part 5:1967. The-combustion of the-waste is done in-an-Oxygen-Charged Bomb-Calorimeter, pressurized at 25 atmospheres (Eyinda & Aganda, 2013); Initial-temperature (Ti) = 16.6°C. From the-thermodynamics of water: Vaporization Temperature (Ts) = 100°C; Heat Capacity of water (Cp) = 4.2 kJ/Kg-K; Latent Heat of Vaporization (Hfg) = 2260kJ/kg; and the-average MC is 36.84%, according to Table 1. The-average mass of moisture (Mw) is therefore 36.84% of 1 kg, which is, Mw=0.3684kg.

Substituting these values in the Net-Energy Equation:
Enet = (1-0.3684)12480 - [0.3684*4.2(100-16.6)) +0.3684*2260] = 7882.368 - [129.043152+832.584] Enet = 6920.7408 kJ/kg.
To-determine the Egross: Enet=E gross−E dry (Eyinda & Aganda, 2013).
But E d r y = H s + H f g E d r y = [m w x (T s − T i ) +(m w x f g )] =0.3684 x 4.2(83.4)+(0.3684 x 2260) =961.6272kJ /kg E g r o s s =6920.7408+961.6272 =7882.368kJ/kg

The-efficiency of heat-production is worked out as: Energy Efficiency=E net/E grossX 100 =87.8% This means that 87.8% of the-solid-waste, at-the-university, has the-capability of being-converted to-heat-energy, through processes such-as: incineration, pyrolysis, and WtE-systems, for generating electricity.
4. Discussion.
4.1. Analysis of Results.
4.1.1. MC.
This study established, that MC ranges from 10.76 to 57.66 %, with an-average of 36.84%. These-findings are in-accord with reports of previous-investigations, which have found MC ranging from 17.73% to as-high-as 82% (see Kalanatarifard & Yang, 2012; Thitame et al., 2010; Kumar & Goel, 2009; Igoni et al., 2007; Cheng et al., 2007; Gidarakos et al., 2006; Mbuligwe, 2002; and The-World-Bank, 1999), although values of 40%-60% are typically observed. Likewise, according-to Tchobanoglous et al. (1993), the-MC of solid-wastes varies, between 15% and 40%, with an-average of 20%. However, MC may reach up to 60% - 70% from-time-to-time, depending, especially, on solid-waste-composition, climate-conditions, and socio-economic-structure of the-particular-region. Mugo et al. (2016), also-stated, mixed-waste MC of 34.72%.

The-results differed, to-some-extent, with-the-findings by: (i) Katiyar et al. (2013), who noted, that MC of municipal-waste varied from 24.3 to 42.2% in-Bhopal, India; (ii) Yildiz et al. (2012), who indicated MC-values ranging from 15 to 40%; (iii) Omari, (2015), who noted that the-MC for Arusha municipal-waste ranges from 55.7 to 64.03%, by weight; (iv) Alhassan & Tanko, (2012), who reported that waste MC, from Nigeria gave 10.25%; (v) Chang et al. (2008), who reported that MC for solid-waste, from Taiwan, ranged from 37.6 to 65.9%; (vi) Ezeah et al. (2015) reported that MC ranges from 43.89 to 55.11, with an-average of 48.80%; and (vii) Das & Bhattacharyya, (2013), also established that MSW at Kolkata, India in-2010 gave MC of 46%, by weight.

It was also revealed, that 41% of the-total-waste, at the-university, fulfilled the-required-values for waste-incineration, without auxiliary-fuel, which should not exceed MC of 50%, as reported by Medina et al. (2013). Burnley (2007) believes that utilizing information, related-to moisture-content enables waste-planners to determine how feasible integrated-solid-waste-management approaches are likely to-be. Chang & Davila (2008), on-the-other-hand pointed-out, that waste-planners need-to-bear in-mind, that the-calorific-value of waste-sample decreases with the-increase in-moisture-content. This study determined 57.66 % moisture-content in food-waste. This is higher, than the-results of Ezeah et al. (2015), obtained from the-food-waste-samples indicating an-average moisture-content of 48.80%. According-to Ozcan et al. (2016), high-organic-matter-content in solid-waste-composition may be a-significant factor, which increases MC. The-findings are in-accord with previous-studies by Ozcan et al. (2016); Yildiz et al., (2012); and Hui et al., (2006). The-relatively-high MC, of food-waste-samples from this-study, might be indicative of waste with lower-calorific-values. The-implication being that bioconversion-technologies, such-as AD, are more-suitable, compared to thermo-chemical-conversion-technologies, such-as combustion or gasification. The-implication of this-result is that with some-balancing, the-food-waste may be amenable to-disposable-options, such-as AD. Besides, according to Tchobanoglous & Kreith (2002), moisture can ruin many-materials, in-a-way, that they are impossible-to-recycle (e.g., if paper and cardboard are lay for long-periods of time, outdoors, and the-materials get wet, and also due-to small-yards, where mixing, and contamination, with other-surrounding-materials can happen).

The-moisture also adversely-affects the-waste-to-energy-conversion-process, as the-process consumes more energy to-evaporate-moisture from SW. Moist-waste, such-as garbage, burns only after-at-least superficial-evaporation of-the-moisture, contained (Buekens, 2005). Therefore, waste-to-energy concept receives less-attention in MSW-treatments, especially in tropical-region, where waste with high-moisture-content has been commonly-reported (Silvennoinen, 2013). However, reduction of moisture of MSW would be-beneficial to-convert-waste into-thermal-energy, effectively and efficiently. Use of solar-energy is a widely-practiced-strategy to-reduce-moisture-content, in-many-materials. For-example, Heshani et al. (2017), suggest a-method to-reduce-moisture in-MSW, by utilizing solar-energy, by developing a-model for moisture-reduction, where the-parabolic solar-energy-concentration-method is applied to-convert solar-energy into thermal-energy.

4.1.2. Volatile-matter.
This study established, that volatile-matter ranges from 21.78 to 51.34%, with an-average of 38.03%. These-findings are comparable with the-results of a-study, carried-out in Kolkata, where volatile-matter of 38.53% was reported. The-results are higher, than the-average volatile-matter of the-three-Indian-cities, with 23.7%; (Shodhganga, 2007). The-finding of an-average volatile-matter is much-lower than the-one, reported by Omari et al. (2014) of 78.9%.

4.1.3. The ash content.
This study determined, that the-waste-ash-content ranges from 14.1 to 42.79%, averaging 23.11%. These-findings are comparable with the-average ash-content from the-three-Indian-cities, that was reported to be 27.7% (25.94% in Chandigarh, and 27.51% in Mohali and 29.9% in Panchkula). Similar-findings had also been observed for a-study carried out in Delhi wherein ash content of 21.8% was reported from LIG-area (Shodhganga, 2007). The-average-finding is higher, than the one reported by Omari et al. (2014) of 10.5%.

These-differences can be due-to different-composition of the-waste, varied weather-conditions, during sample-collection, and the-procedure, followed, in determination of the-parameters, among-other- reasons.
4.2. Assessment of combustibility.

MSW can be classified into ‘dry’ and ‘wet’ materials, on the basis of their moisture content. From the perspective of energy recovery, the ‘dry’ fraction can be divided into (Themelis et al., 2002): (i) combustible materials, such as paper, plastics, wood, etc.; and (ii) non-combustible or ‘inert’ materials, such as metal and glass. There are three options for handling the ‘wet’ fraction: (a) combustion; (b) aerobic, or anaerobic bioconversion; and (c) land filling. From Starovoytova (2018c), combustibles, in the university waste, constitute approximately 78% (on subtracting 22% of inert materials from the total waste).

According to the Tanner triangle, the wastes that are theoretically feasible for combustion, without auxiliary fuel, should have met the following limits: Moisture content < 50%; Ash content < 60%; and Combustible fraction > 25% (BSI, 2011). These limits inform the combustible area, shown in Figure 3 as grey shaded region. The average values, for the moisture content and ash, presented in Table 1, are plotted in a Tanner triangle diagram, alongside with approximated Combustibles of 78% (see Figure 3 in red), to see where it falls within the grey shaded area indicating a combustible fraction.

![Figure 3: Waste combustibility plot.](image)

The solid waste, generated in the university, however, consists of considerable moisture (57.66%), and hence, cannot be combusted, without auxiliary fuel, but can be considered for composting. Besides, the unpleasant odors and liquids, associated with ‘garbage’ are due to the putrescible organic components of food and plant wastes in the ‘wet’ stream. These materials are less than 40% of the total MSW at the campus; yet they contaminate and complicate the transport and processing of the rest of the MSW. Therefore, it is generally preferable to separate the ‘wet’ and ‘dry’ components, at the source. This is already being done at some forward looking communities in Canada, Europe, and Australia (Guvenc, 2016).

The next section provides some details on conventional composting, as well as vermicomposting.

4.3. Composting and vermicomposting.

Composting is increasingly-used method to treat any type of organic waste (REA, 2011; IEA, 2003). For example, Chandak (2010) described a successful community-based model of composting across several cities and towns in Bangladesh. The project reduced the land filling budget of the city, valuable resource was recovered from organic waste, in the form of compost, and the project also created assured revenue for 10 years, through sale of compost. 800 jobs were also created for poor urban residents, and 50,000 metric tons of compost was produced every year, for more sustainable farming. The project avoids greenhouse gas emissions in the amount of 89,000 tons of CO₂-equivalent, per year. The project has also resulted in behavioral changes, in urban communities, which were actively involved in the project, as they became convinced about the resource value of waste. The main challenges to the project were the lack of a policy mechanism, to create opportunities for developing public-private partnerships, and absence of the practice of source separation of waste, at the household level.

In addition, numerous studies (see REA, 2011; IEA, 2003) have recommended that composting, or even vermicomposting, can play a vital role in organic waste management, and in turn improve agricultural soil fertility. According to Starovoytova (2012), the climate of Kenya is, in some ways, ideal for aerobic degradation of wastes. According to Peasey (2000), year round temperatures, above 20°C, ensure, that the waste material will be exposed to conditions, that promote evaporation of moisture, from the wastes, and conditions, which are favorable, for pathogen destruction.
The-term **vermicomposting** means the-use of earthworms, for-example, epigeic-compost-worms, such-as *Eisenia fetida*, *Lumbricus rubellus* and *Eudrilus eugeniae*, for composting organic-residues. Earthworms can consume practically-all-kinds of organic-matter and they can-eat their-own-body-weight, per-day, e.g., 1 kg of worms can-consume 1 kg of residues, every-day (Aalok et al., 2008). The-excreta (castings) of the-worms are rich in-nitrate. Vermicomposting, can be further-enhanced with cow-urine; undiluted-urine can-be-used for moistening organic-wastes, during the-preliminary-composting-period (before the-addition of worms.). After the-initiation of worm-activity, urine can-be-diluted-with an-equal-quantity of water, yielding vermicompost with a-higher N-content, in much-shorted-period, in-comparison-with traditional-composting (Munroe, 2004).

On-the-other-hand, traditional-thermophilic-composting characterized by long-duration of the-process, frequent-turning of the-material, loss of nutrients, during the-prolonged-process, and the-heterogeneous resultant-product. However, the-main-advantage of traditional-composting is that the-temperatures, reached during the-process, are-high-enough (over 70 °C), for an-adequate-pathogen-kill.

In-vermicomposting, the-earthworms take over the-roles of turning and maintaining the-material in an-aerobic-condition, thereby reducing the-need for mechanical-operations. In-addition, the-product (vermicompost) is homogenous. However, the-major-drawback of the-vermicomposting-process is that the-temperature (less than 35 °C) is not high-enough, for an-acceptable-pathogen-kill. A-study by Ndegwa & Thompson (2001), has examined the-possibility of integrating traditional-thermophilic-composting and vermicomposting, with promising-results.

This-study also revealed, that 41% of the-total-waste is combustible; and 87.8% of the-solid-waste has the-capability of being-converted to heat-energy. The-(WtE)-technologies for such-waste are elaborated on in the-next-section.

### 4.4. WtE-technologies.

#### 4.4.1. Classification.

Energy-conversion from-waste (waste-to-energy (WtE)) can be-obtained by utilizing different-technologies. Each-one of these WtE-solutions has specific-characteristics, and can-be more or less feasible, depending on many-parameters, including: the-type and composition of waste, its-energy-content, the-desired final-energy form, the-thermodynamic and chemical-conditions, in-which a-WtE-plant can operate, and the-overall energy-efficiency. **Figure 4** shows the-operational-principle and output(s) of the-three-main WtE technologies (thermo-chemical, bio-chemical, and chemical) with their-sub-technologies, and it gives an-overall-picture of the-available-options on the-market. There are also new-developments and research projects, aimed at promoting *alternatives* to-the-most-mature and established-technologies.

The-following-sections provide more-information on the-three-main WtE-technologies.

#### 4.4.2. Thermo-chemical-Conversion.

Thermo-chemical-conversion-technologies are used to-recover-energy, from MSW, by-using, or involving, high-temperatures. The-dry-matter, from MSW, is most-suitable-feedstock for thermo-chemical-conversion technologies.

According-to Ellyin (2012), there are three-**principal**-ways to-recover the-energy-content of MSW, by treating it thermally; *via* pyrolysis, gasification, and combustion/incineration. These-processes are differentiated by the-ratio of oxygen, supplied to the-thermal-process, divided by oxygen, required for complete-combustion. This-ratio is defined as the ‘lambda’ ratio ($\lambda$), and in-the-case of pyrolysis, it-is equal to zero. Gasification is conducted at sub-stoichiometric-conditions and full-combustion is carried-out, using a-lambda greater than one. Simply put: Pyrolysis $\lambda = 0$, no air, all-external-heat; Gasification $\lambda = 0.5$, partial-use of external-heat; and Combustion $\lambda = 1.5 +$, no external-heat. Where $\lambda$ represents: oxygen input/ oxygen, required stoichio-metrically, for complete-oxidation, of all-organic-compounds in-MSW.
4.4.2.1. Incineration.

Combustion/incineration of MSW is the complete oxidation of the combustible materials, contained in the solid-waste-fuel; the process is highly exothermic (Consonni & Viganò, 2012). MSW-incineration is the burning of waste, in a controlled process, within a specific facility, that has been built for this purpose. The primary goal of waste-incineration is to reduce MSW-volume and mass, and also make it chemically inert, in a combustion-process, without the need of additional fuel (autothermic combustion). It also enables recovery of energy, minerals, and metals, from the waste-stream (EU, 2006). Untreated MSW is simply incinerated in mass-burn systems. The heat, given-off, is converted into steam, which can then be passed through a turbine, to generate electricity (co-generation, or combined-heat, and power-plants), or to produce both; electricity and low-temperature heat, suitable for space heating (Kumar, 2000).

The combustible materials, in waste burn, when they reach the necessary ignition-temperature and come into contact with oxygen, undergoing an oxidation-reaction. The reaction temperature is between 850 and 1450°C, and the combustion process takes place in the gas and solid-phase, simultaneously, releasing heat energy. After the waste incineration process, superheated steam is produced, and then it is used within a cogeneration system, to produce energy and heat (Tan et al., 2013). The electric energy is produced by a turbine, connected to a generator, and the heat, by a district-heating system. The highest environmental impact of MSW incineration is the production of greenhouse-gas emissions (GHG-E), causing public health concerns (Ashworth et al., 2014). Besides, there are always about 25% residues, from incineration, in the form of slag (bottom ash) and fly-ash. Bottom-ash is made up of fine particulates, that fall to the bottom of the incinerator, during combustion, whilst fly-ash refers to fine particulates, in exhaust gases, which must be removed, in flue-gas treatment. These residues need further attention and, in the case of the hazardous fly-ash, a secure-place for final disposal. Depending on the bottom-ash treatment options, ferrous and non-ferrous metals can also be recovered, and the remaining ash can be further enhanced to be used for road construction and buildings (Grosso et al., 2011).

In order to implement incineration system, the lower calorific value of MSW must be at least 7 MJ/kg, and must never fall below 6 MJ/kg in any season, and stable combustible waste supply (i.e., at least 50,000 metric tons/year) should be maintained (Dolgen et al., 2005). At the university context, these mandatory criteria cannot be fulfilled, and hence, the incineration plant should not be implemented. Moreover, in addition to high capital and operation costs, of incineration facilities, they do emit harmful substances to both the environment and human health, such as: acidic gases (hydrochloric acid (HCl), hydrofluoric acid (HF), sulphuric acid (H₂SO₄)); particulates; oxides of nitrogen (NOₓ); organic compounds (dioxins and furans); and carbon dioxide. Also, the ash contains toxic elements such as: arsenic, cadmium, lead, and mercury, and treating the ash, for the pollutants beyond limit is another costly affair (Kuras, 2009). Moreover, technology-wise, critics argue that incinerators destroy valuable resources and they may also reduce incentives for recycling (Zhang et al., 2012; and Klein, 2002).
4.4.2. 2. Gasification.
Solid-waste-gasification is the-partial-oxidation of waste-fuel, in the-presence of an-oxidant, of lower-amount, than that required for the-stoicho-metric-combustion (Thakare& Nandi, 2016; Eremed et al., 2015; Higman & Burgt, 2011), within high-range of working-temperatures (700-900°C) (Arena & Di Gregorio, 2013). The-gasification process breaks-down the-solid-waste, or any-carbon-based waste-feedstock, into-useful-by-products, that contain a-significant-amount of partially-oxidized-compounds, primarily a-mixture of carbon-monoxide, hydrogen, and carbon-dioxide. Furthermore, the-heat, required for the-gasification-process, is provided either by; partial-combustion, to-gasify the-rest, or heat-energy is provided, by using an-external-heat-supply (Higman & Burgt, 2011). The-produced-gas, which is called syngas, can be used for various-applications, after syngas-cleaning-process, which is the-greatest-challenge to-commercialize this-plant in-large-scale (Arena, 2012). Once the-syngas is cleaned, it can be used to-generate high-quality-fuels, chemicals, or synthetic-natural-gas (SNG); it can be used in a-more-efficient gas-turbines and/or internal-combustion-engines, or it can be burned, in a-conventional-burner, which is connected to a-boiler and steam-turbine (Albrecht, 2015). It-is-important to-note, that the-heterogeneous nature of the-solid-waste-fuel, mechanical-treatment, ahead of gasification, sensitivity to feedstock properties, low-heating-value of waste-fuel, costly-flue-gas clean-up-systems, difficulty of syngas clean-up, and poor-performance at small-scale, have been a-great-challenge, during-gasification of MSW (Consonni, & Viganò, 2012; Oliveiraa & Rosa, 2003).

4.4.2. 3. Pyrolysis.
Pyrolysis of solid-waste is defined as a-thermo-chemical-decomposition of waste-fuel at-elevated temperatures, approximately between 300°C and 800°C, in the-absence of air, and it converts MSW into gas (syngas), liquid (tar) and solid-products (char). In-this-technology, waste requires the-mechanical-separation of glass, metals, and other-inert-materials. Syngas, gas produced during- pyrolysis-process, is mainly composed of methane, hydrogen, carbon monoxide, and carbon-dioxide. The net-calorific-value of syngas is normally between 15 and 20 MJ/Nm³ (Zafar, 2014). In-addition, a-recent-study found that after distillation of liquid-hydrocarbons (from the-pyrolysis of plastic-waste), the-resulting-synthetic-product has the-same-properties as the-petro-diesel-fuel (Agarwal et al., 2013). The-amount of useful-products from pyrolysis-process (CO, H₂, CH₄, and other-hydrocarbons) and their-proportion depend entirely on the-pyrolysis-temperature and the-rate of heating (D’Alessandro et al., 2013; Higman & Burgt, 2011).

4.4.3. Biochemical-Conversion.
Biological-conversion-technologies utilize microbial-processes to-transform-waste, and are restricted to biodegradable-waste, such-as, food and yard-waste. Accordingly, the-wet-matter from the-MSW (the-biogenic-fraction) and agricultural-waste are the-most-suitable feed-stocks for biochemical-conversion-technologies.

4.4.3.1. Fermentation.
Fermentation is a-process, by which organic-waste is converted-into an-acid or alcohol (e.g., bio-ethanol, lactic-acid, hydrogen) in the-absence of oxygen, leaving a-nutrient-rich-residue. The-by-product of ethanol-fermentation is residual-silage, after distillation, and is usually-used for animal-feeding, with recent-focus on finding-ways to-recycle the-energy, contained in-it. Practical bio-ethanol-fermentation-plants are large, and-are-suitable-sized-plants produce about 200,000-300,000 tons of ethanol, per-year (Braun et al., 2010). By-using-yeast, the-biomass-fraction of MSW, can be fermented, to-generate ethanol, which can be used to-run internal-combustion-engines (Vitez et al., 2000).

4.4.3.2. Anaerobic Digestion.
AD is only suitable for processing organic-matter, i.e. biomass. AD is a-process, by-which organic-material is broken-down, by micro-organisms, in the-absence of oxygen, producing biogas, a-methane-rich-gas used as a-fuel, a-digestate, a-source of nutrients, used as fertilizer, and decontaminated-water (Di Maria et al., 2017). AD utilizes the-biological-processes of many-classes of bacteria, and generally consists of four-steps: hydrolysis, acidogenesis, acetogenesis, and methanogenesis (Xu et al., 2002). For that-purpose a-gas-tight-reactor, a so-called anaerobic-digester, is used, to-provide favorable-conditions for microorganisms, to-turn organic-matter, the-input-feedstock, into-biogas and a-solid-liquid-residue called digestate. Biogas is a-mixture of different-gases, which can be-converted into thermal and/or electrical energy. The-flammable-gas methane (CH₄) is the-main-energy-carrier in-biogas, and its-content ranges between 50 – 75%, depending on feedstock and-operational-conditions (Welling er et al., 2013). Due-to its-lower-methane-content, the-heating-value of biogas, is about two-thirds that of natural-gas (5.5 to 7.5 kWh/m³). Another-option is to-upgrade biogas to bio-methane, with approximately-98% methane-content, which can be used as a-substitute for natural-gas (Welling er et al., 2013).

The-time of operation, per-cycle, meaning how-long it takes for the-organic-waste to-be-processed by an-AD-plant, is usually 15 to 30 days (Bayard et al., 2010). The-biogas, naturally-created, in sealed-tanks, is utilized, to-generate renewable-energy, in the-form of electricity, or heat, with a-combined-heat, and power-unit (CHP). The-bio-fertilizer is pasteurized, to-make-it pathogen-free, and can-be-applied twice-a-year on-farmland, successfully-replacing the-fertilizers, derived from fossil-fuels. The-technology is widely-used to-treat-
Gas-emissions, from landfills and waste-dumpsites, around the-world, are causing global-environmental impacts. Methane, one of the-gasses, emitted, is a-potent-greenhouse-gas, with a-global-warming potential that is 25 times greater-than CO₂. A-study by Themelis & Ulloa (2007) showed, that worldwide, landfills produce about 75 billion Nm³ of landfill-gasses, and less than 3% of this-potential is used, to-produce energy or heat. Capturing methane-emissions from landfills is not only beneficial, for the-environment, as it helps mitigate climate-change, but also for the-energy-sector and the-community.

The-process, of capturing the-gasses, involves partially-covering the-landfill and inserting collection-systems, with either vertical or horizontal-trenches. As-gas-travels, through the-collection-system, the-condensate (water) formed, needs-to-be-accumulated and treated. The-gas will be-pulled from the-collection-wells into the-collection-header, and sent to-downstream-treatment, with the-aid of a-blower. The-excess-gas will be-flared in-open, or enclosed-conditions, to-control emissions, during start-up, or downtime, of the-energy-recovery-system, or to-control the-excess-gas, when the-capacity for energy- conversion is surpassed. Applications for LFG include direct use in boilers, thermal uses in kilns (cement, pottery, bricks), sludge-dryers, infrared-heaters, blacksmithing-forges, leachate-evaporation, and electricity- generation, to-name a-few. LFG is increasingly-being-used for heating of processes, that create fuels, such- as biodiesel or ethanol, or directly-applied, as feedstock for alternative-fuels, such-as compressed-natural- gas, liquefied-natural-gas, or methanol. The-projects, that use cogeneration (CHP), to-generate electricity and capture the-thermal-energy are more-efficient and more-attractive in this-sense (Mostbauer et al., 2014).
4.4.3.4. Microbial Fuel Cells (MFCs).

MFCs are biochemical-catalyzed-systems, in which electricity is produced, by oxidizing biodegradable organic-matters, in the-presence of either; bacteria or enzyme (Rahimnejad et al., 2015). Bacteria are more-likely to-be-used in-MFCs, for electricity-production, which also-accomplish the-biodegradation of organic-matters and wastes. Good-sources of microorganisms include: marine-sediment, soil, wastewater, fresh-water-sediment and activated-sludge. MFCs consist of anodic and cathode-chambers, separated-by a-proton-exchange-membrane. The-anodic-part is usually maintained, in the-absence of oxygen, while the-cathodic can-be-exposed to-air, or submerged in aerobic-solutions. Electrons-flow, from the-anode to-the cathode, through an-external-circuit, that usually contains a-resistor, a-battery, to-be-charged, or some-other-electrical-device. More-information on practical-use of MFCs can be-obtained via Starovoytova et al. (2014). MFCs are affordable and usually-used in-small and medium-size-facilities, and hence, the- technology is potentially-appropriate in the-university, subject to further-independent-assessment.

4.5. Chemical Conversion.

Under Chemical-Conversion, the-esterification-process involves the-reaction of a-triglyceride (fat/oil) with alcohol, in-the-presence of an-alkaline-catalyst, such-as sodium-hydroxide. A-triglyceride has a-glycerine-molecule, as its-base, with three-long-fatty-acids, attached. The-alcohol reacts with the-fatty-acids, to-form a-mono-alkyl-ester, or biodiesel, and crude-glycerol, used in-the-cosmetic, pharmaceutical, food, and painting-industries. The-alcohol used is usually either; methanol, which produces methyl-esters, or ethanol, with ethyl-esters. The-base, applied for methyl-ester, is potassium or sodium-hydroxide, but for ethyl-ester the-former-base is more-suitable. The-esterification-reaction is affected by the-chemical-structure of the-alcohol, the-acid, and the-acid-catalyst. Biodiesel is used in the-transportation-sector, and can be produced from oils and fats, through three-methods: (i) base-catalyzed trans-esterification of oil; (ii) direct acid catalyzed trans-esterification of oil; and (iii) conversion of the-oil to its-fatty acids, and then to biodiesel. Base-catalyzed trans-esterification is the-most-economical-process http://www.see.murdoch.edu.au/info).

Moreover, so-called Emerging-technologies, include: Hydrothermal-Carbonization (HTC); Palletization; Wet-oxidation; freezing (of sludge) (Buekens, 2005); and Dendro-Liquid-Energy (DLE).

From the-above-information, and considering relatively-small-waste-generation-rates, and limited-finances, available, at the-university, a combination of composting, vermin-composting, and bio-methanation plant, incorporating Microbial-Fuel-Cells (MFCs), would help in achieving a better SWM-system. These-technologies were-chose, for further-examination, on-the-basis of lower-capital-cost (ton/year), net-operational-cost, per-ton, complexity of technology, and higher-efficiency, as-compared to-plasma-arc gasification and pyrolysis (Ouda et al., 2015; Sorenson, 2010; Clark & Rogoff, 2010; Greater London Authority, 2008).

More-details, for each of the-listed-technologies, including: Diagram, suitable-waste, operational, legal, economic, and environmental-aspects, can be accessed via Mutz et al., (2017); and World-Energy- Council (2016). In-addition, any-WtE-project is a-complex-undertaking and should-be-accompanied by a-professional and thorough feasibility-assessment. The-decision-matrix (with 12 parameters) presented in Mutz et al. (2017), can assist in-the-examination, of the-suitability of potential-technologies, for specific- contexts. The-study, hence, recommends to-conduct a-feasibility-assessment of WtE-technologies, at the-university, via the-decision-matrix.

4.6. Concluding remarks on WtE.

Waste-to-energy technologies (WtE) are promising technologies, especially for developing-countries, to-turn waste into a-useable-form of energy (El-Fadel et al., 2002). Harnessing-energy, from waste, has many-benefits, such-as (Kothari et al., 2010; Greenwood, 2009; Wang, 2009; Kathiravale, 2003; and Voelker, 1997): (i) It helps to-reduce dependency on-energy-imports; (ii) It contributes towards reducing carbon-emissions and meeting-renewable-energy-targets. In-fact, by the-world-economic-forum report “Green Investing: Towards a Clean Energy Infrastructure” published in-2009, WtE is identified as one of the-eight-technologies, having significant-potential to-contribute to-future low-carbon-energy- system; (iii) When used for electricity-generation, these-technologies have a-steady and controllable-output, sometimes referred-to-as providing ‘base-load’ power; (iv) It has very-good-sustainability and greenhouse-gas saving-characteristics, as it makes further use of materials, that have-already-been-discarded; (v) reduces the-land-pressure-problem; (vi) create green-jobs; (vii) reduces the-cost of waste-transportation; and (ix) reduces use of precarious-energy-resources by-the society.

On-the-other-hand, it is paramount, that recyclable-material is removed first, and that energy is recovered only from what remains, i.e. from the-residual-waste. In-addition, WtE can never solve the- problem alone, but rather needs-to-be-embedded in an-integrated SWM-system, that is tailored to the-specific-local-conditions, with regards-to waste-composition, collection and recycling, informal-sector participation, environmental-challenges, financing, resource-prices, and other-aspects.

It is also important to-be-aware of several-common-myths, which persist around WtEs, such-as:

Myth 1: “WtE is an easy going solution to get rid of all the waste problems in a city”
The situation is much-more complex, and WtE needs professional-planning, construction, and operation. Unfortunately, there are several-companies, on-the-market, which are inexperienced with the conditions in-developing and emerging-countries. Decision-makers need-to-be-aware that their-objective is first and foremost to 'sell' their-product, and not to solve-the-local-problem of SWM.

**Myth 2:** *A WtE plant can finance its costs exclusively through the sale of recovered energy*  
In-Europe, where calorific-values of waste, and energy-prices, are higher, the-revenue, from non-subsidized sale of energy (in-form of heat and power) might cover operating-costs, but never the-entire-investment and capital-costs.

**Myth 3:** *With a WtE plant in operation, a big fraction of the energy demand of a city can be covered*  
In-reality, energy from household-waste will only be able to-contribute a-small-fraction, to-the-overall electricity-demand of a city (~ 5%). Utilization of heat is the-most-efficient-application in-Europe, but hardly-used in-developing-countries.

**Myth 4:** *You can make gold from garbage; even unsorted waste can be sold with profit to be used for further energy and material recovery*  
In-reality, WtE is not a-business-model, which generates cost-covering-incomes. Revenues, from energy-sales help-to-cover part of the-overall-costs, of thermal-treatment, but additional-gate-fees, or other forms of revenues, are required, to-cover full-costs. In all-countries, waste-management as a-whole, has costs and cannot be considered, as a-profitable-business that could depend, exclusively, on-the-sale of energy, Refuse Derived Fuel (RDF), and recycling-materials, at current-prices, for these-products.

**Myth 5:** *Qualified and experienced international companies are queuing up to invest and operate large WtE plants in developing and emerging countries at their own risk*  
This is only partly-correct, as experienced-international-companies are presently-reluctant to-invest in-WtE, in developing and emerging-countries. The-legal, financial, and reputational-risks, are high, and any-project of the-private-sector has to-be-bankable.

These myths are often-kept-alive, and can-obstruct informed-discussions. Besides, WtE-projects are expensive, and constitute a-substantial-financial-risk, for the-university. An-independent-assessment of costs and a-profound-understanding on financial-implications are, therefore, crucial for informed-decision making.

Future-oriented WM-concepts should fulfill economic and ecological-needs. Within this-context, pyrolysis or gasification of high-calorific-waste-fractions (sometimes referred-to-as ATTs (Advanced Thermal Treatments), can offer, in-combination-with power-plants and industrial-furnaces, an-alternative-technical-solution, provided that it-is mainly used for selected-high-calorific waste. The-technical-approach represents a-possible-choice, within an-already fully-organized WM-system. However, according-to the-United-Nation Framework-Convention on Climate-Change (UNFCCC): “… in most if not all developing countries the conditions do not exist in a municipal set-up which justifies the application of pyrolysis or gasification. In addition the relatively high operation and investment costs do not justify experimenting with a niche technology for very selective fractions which are seldom found in municipal waste”. For-example, on-average, the-capital-investment of WtE plants is approximately three times higher than the present coal-fired power plants (Themelis & Reshadi, 2009). In-this REGARD, reduction of waste; separation of waste, at-the-source; recovery of materials; recovery of energy; and bioconversion, should be-considered, at-the-university, first.

5. Conclusion and Recommendations.
The study established that, for the-subject-waste: (a) MC ranges from 10.76 to 57.66 %, with an-average of 36.84%; (b) Ash-content ranges from 14.1 to 42.79%, averaging 23.11%; (c) Volatile-matter-ranges from 21.78 to 51.34%, with an-average of 38.03%; (d) From the-graphical-assessment of the-Tanner triangle, it was projected that: (i) 37% by weight, of the-total-waste, is high in-moisture-content (57.66%), and according to the-Tanner-combustibility-requirements cannot be combusted, without auxiliary- fuel (e.g., autothermic-combustion); and (ii) 41% of the-total-waste is combustible; and (e) 87.8% of the-solid-waste has the-capability of being-converted to heat-energy.

Potential of WtE-technologies, for the-campus-waste, were also-examined; it-is-important to-emphasize, however, that WtE-projects should not compete with waste-reduction and cost-efficient-reuse and material-recycling-measures. WtE is largely a-complementary-technology, for the-treatment of remaining/residual non-recyclable MSW-fractions.

**Recommendations:**
(a) Food-waste should-be-composted, or vermicomposted, or anaerobically-digested, to-generate biogas, and produce a-stabilized-organic-humus, or Microbial-Fuel-Cells (MFCs) can-be-used for electricity-production.
(b) ‘Wet’ and ‘dry’ waste-fractions should be separated, at source.
Besides, the-current-study is largely-preliminary, therefore, further-studies, are recommended, such-as:
(i) Proximate and Ultimate-Analysis of solid-waste, generated by the-university.

The-findings of this-research provide a-necessary-baseline-data, for the-four-subsequent-studies, in-the-series, and also, hopefully, add to-the-body of knowledge, on the-subject-matter.

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